

BEYOND EINSTEIN: From the Big Bang to Black Holes

# Constellation

*The Constellation X-Ray Mission*

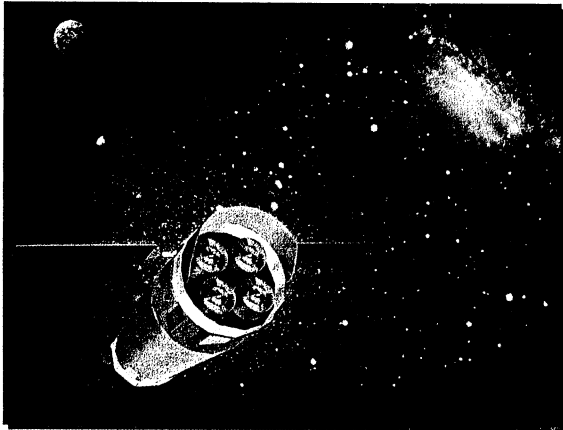
## ►► The Constellation-X Mission

Jean Cottam  
(NASA/GSFC)

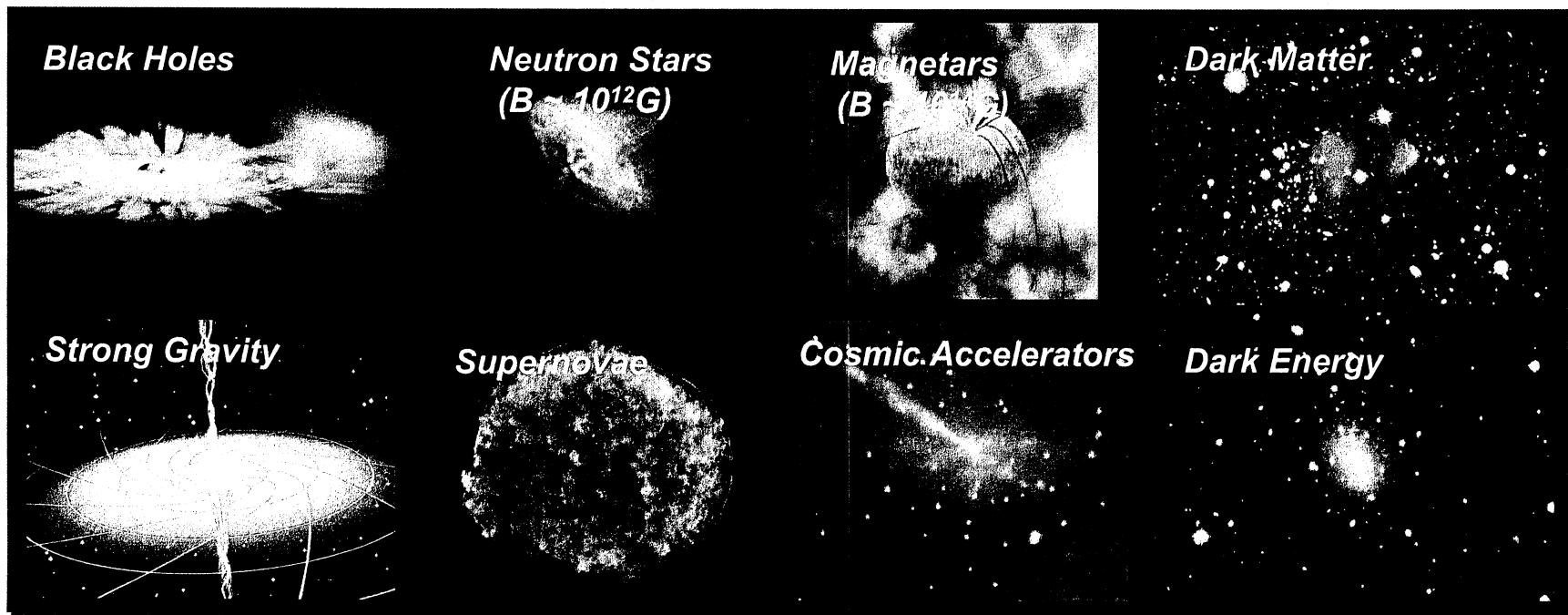
Astrophysics of Compact Objects  
Huangshan City, China  
July 2007



# Constellation-X Will Open a New Window on X-ray Spectroscopy



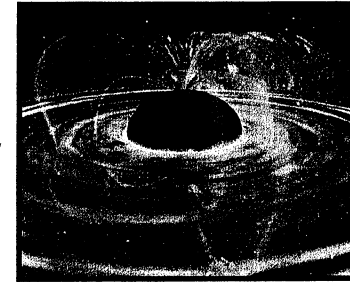
- X-ray emission probes the physics of extreme processes, places and events.
- Chandra and XMM-Newton brought x-ray astronomy to the forefront
- Con-X throughput for high resolution spectroscopy is 100 times higher than Chandra and XMM  
⇒ X-ray astronomy becomes X-ray astrophysics



## Driving Science Objectives

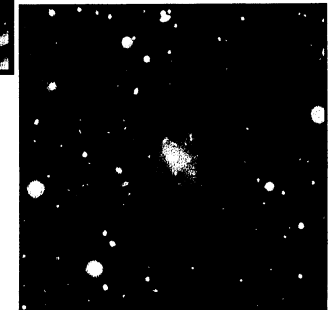
### *Black Holes*

- Use black holes to test General Relativity and measure black hole spin



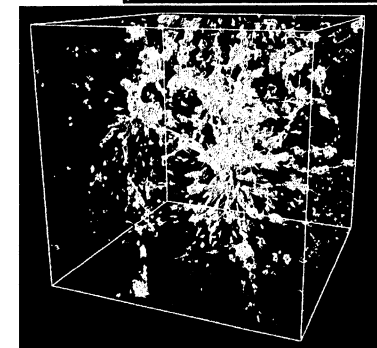
### *Dark Energy (and Dark Matter)*

- Use Galaxy Clusters to provide factor of ten improvement in key Dark Energy (DE) parameters



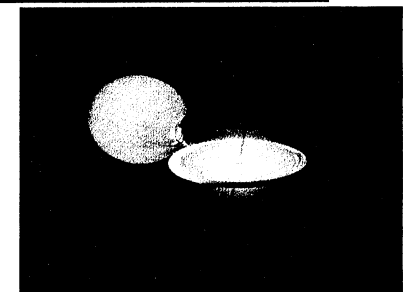
### *Missing Baryons*

- Unambiguous detection of the hot phase of the Warm-Hot Intergalactic Medium (WHIM) at  $z > 0$



### *Neutron Star Equation of State*

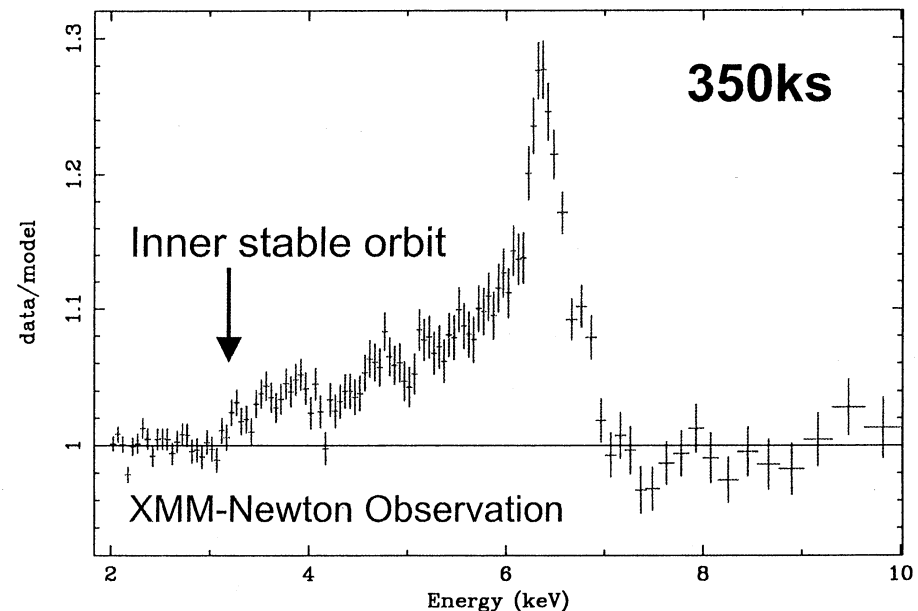
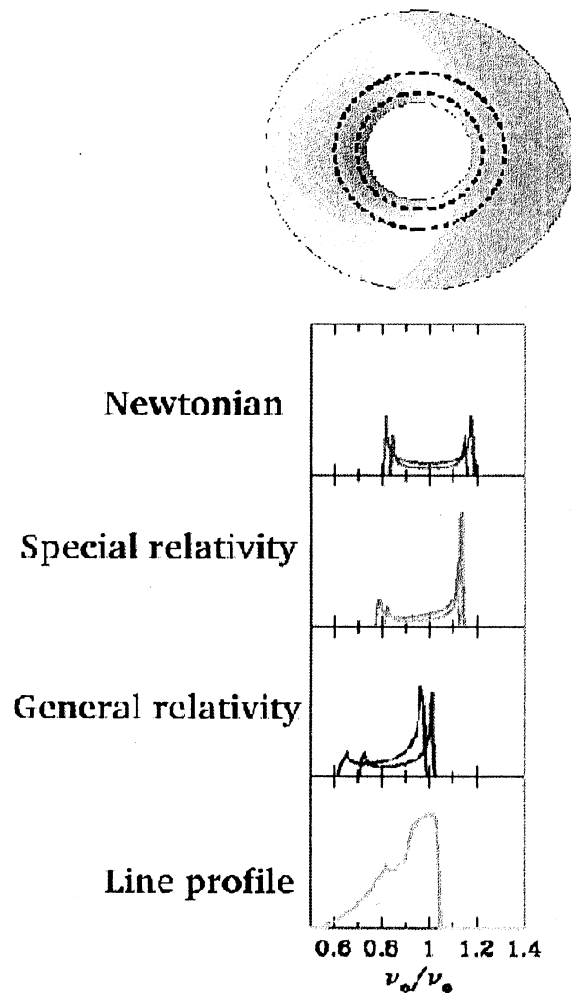
- Measuring the mass-radius relation of neutron stars to determine the Equation of State (EOS) of ultra-dense matter



## Black Holes: Accretion Disks and X-ray Reflection

The Iron fluorescence emission line is created when X-rays scatter and are absorbed in dense matter, close to the event horizon of the black hole.

MCG-6-30-15

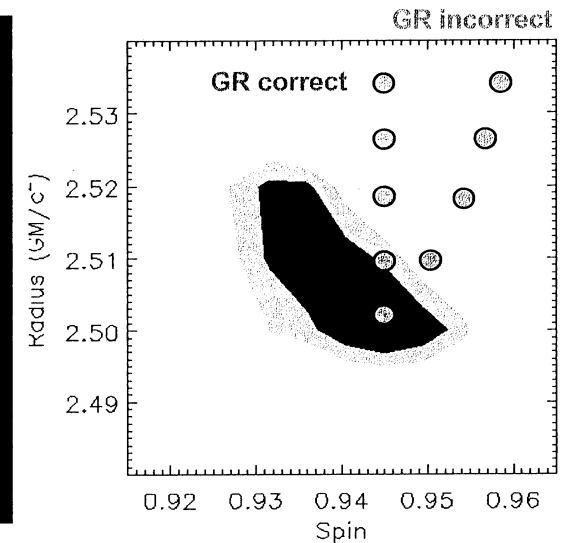
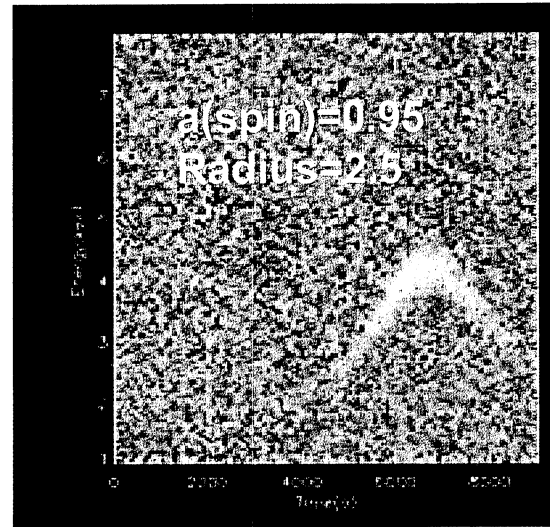


- Relativistically broadened iron K lines have been detected from within 6 gravitational radii of Black Holes by ASCA, XMM-Newton, Chandra and Suzaku
- Further progress towards using this feature as a strong gravity diagnostic requires Constellation-X

## Black Holes

*Use black holes to test General Relativity (GR) and measure black hole spin*

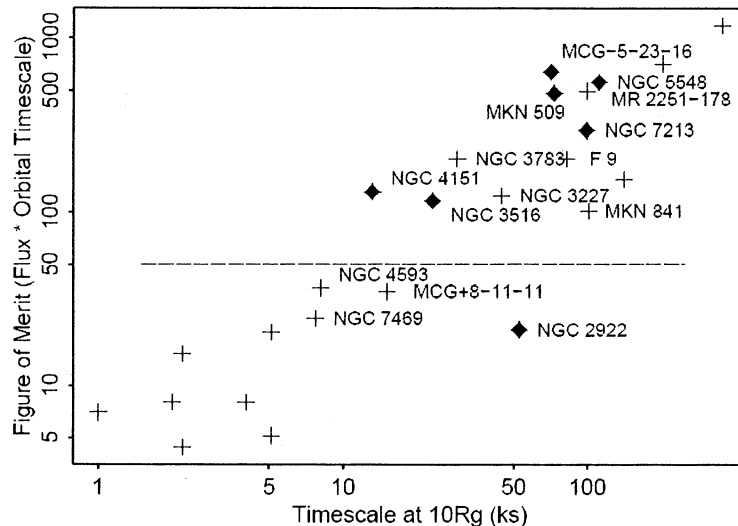
- Con-X will probe close to the event horizon with 100× better sensitivity to:
  - Follow dynamics of individual “hot spots” to determine spin as a function of radius in disk.
  - Spin measurements vs radius provide a powerful consistency check of GR in the strong gravity regime.



*Detectability depends on X-ray flux, line intensity, and orbital timescale (FOM)*

*Key to GR tests with hot spots:  
large collecting area and good  
spectral resolving power*

## Black Holes: Measurements

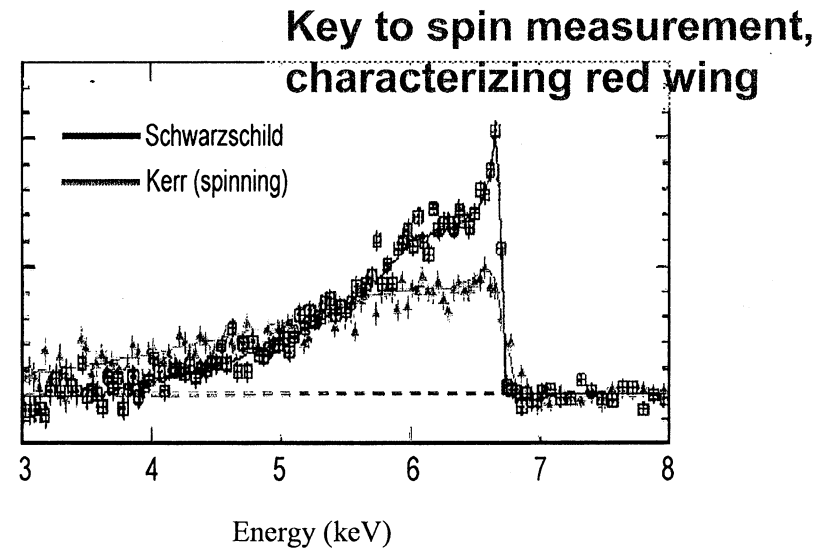


ASCA X-ray sample of AGN

### Time-variable Fe K measurements

- Target list for GR tests known and growing
- Single target sufficient to test GR under strong gravity
- Currently >dozen targets over FOM requirement
- Range of masses at least 1, perhaps 3 orders of magnitude

Detailed characterization of broad FeK line to measure spin for several hundred AGN over a range of luminosity and redshift

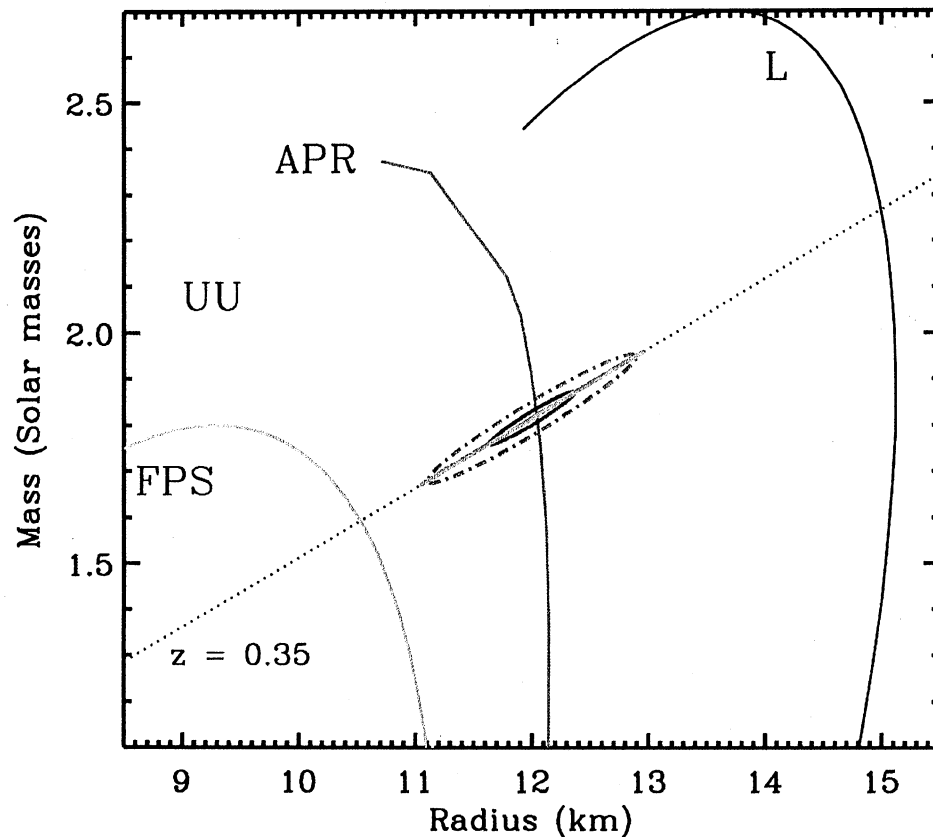


### Continuum Is Key For Spin Measurements:

- Require 150 cm<sup>2</sup> at 10-40 keV
- Spectral resolving power R=2400 required to resolve warm absorber (permits continuum to be measured)

## Neutron Stars

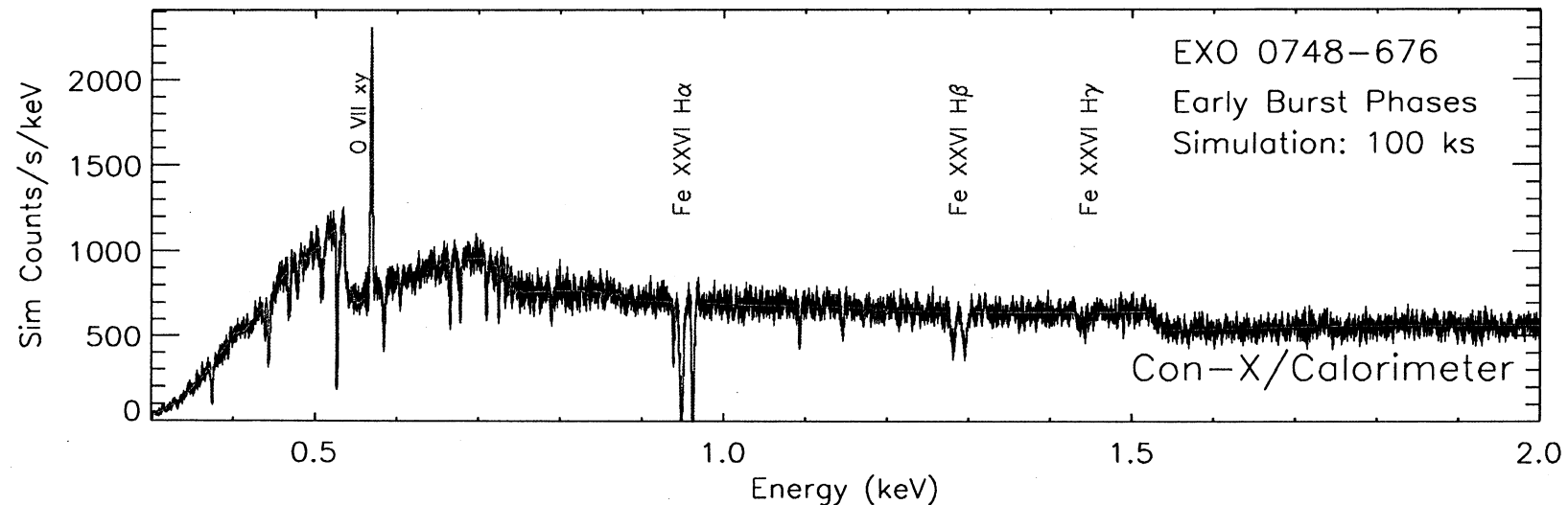
*Measuring the mass-radius relation of neutron stars to determine the Equation of State (EOS) of ultra-dense matter*



- NS contain the densest states of matter in the universe.
- The nuclear physics that governs the interactions between constituent particles predicts mass/radius relations.
- X-ray bursts from LMXBs provide ideal conditions for measuring the Equation of State for neutron stars.
- Con-X will provide high S/N atmospheric absorption spectra, and measure burst oscillations for a large sample of neutron stars covering a range of masses.

# Neutron Star EOS

*Two measurement techniques:*



## Measurement #1 – Absorption spectroscopy:

- Absorption spectra provide a direct measure of gravitational redshift at surface of the star ( $z \propto M/R$ ).
- The measured widths of the lines constrains the NS radius to 5-10% (compare to best present constraints: 9.5-15 km for EXO 0748-676).

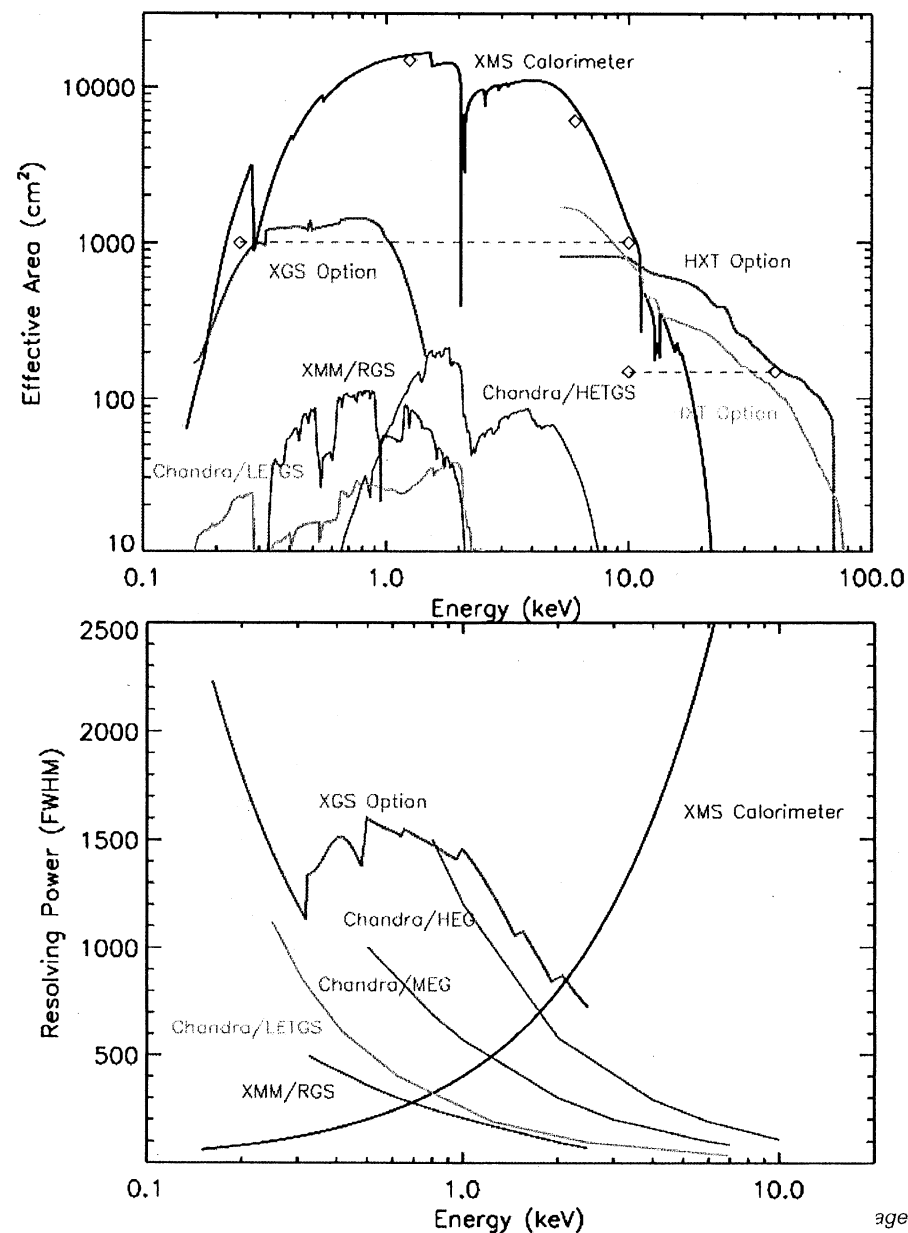
## Measurement #2 – Burst oscillations:

- Pulse shapes of burst oscillations can provide an independent measure of the mass and radius to a few percent. Requires 100 microsec timing and ability to handle count rates up to 0.25 Crab.



## Science Objectives Flow Into Key Performance Requirements

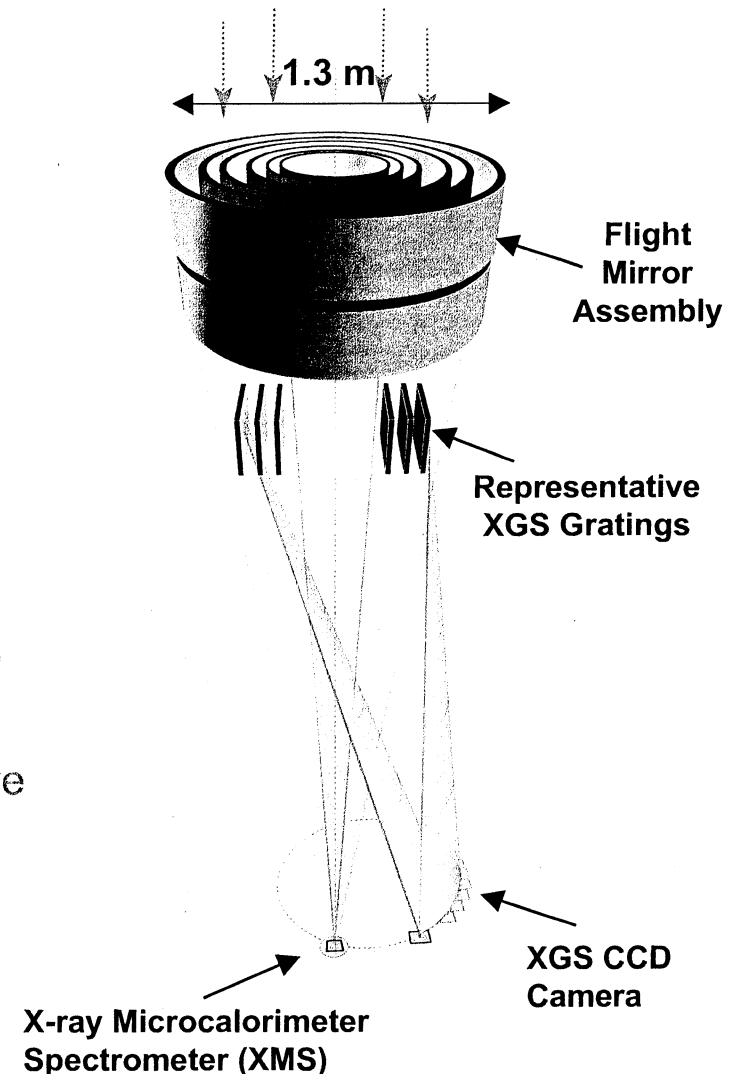
|                             |  |
|-----------------------------|--|
| <b>Bandpass:</b>            | 0.3 – 40 keV   |
| <b>Effective Area:</b>      | 15,000 cm <sup>2</sup> @ 1.25 keV<br>6,000 cm <sup>2</sup> @ 6 keV<br>150 cm <sup>2</sup> @ 40 keV |
| <b>Spectral Resolution:</b> | 1250 @ 0.3 – 1 keV<br>2400 @ 6 keV   |
| <b>Angular Resolution</b>   | 15 arcsec 0.3 – 7 keV<br>(5 arcsec goal)<br>30 arcsec 7.0 – 40 keV                                 |
| <b>Field of View</b>        | 5 x 5 arcmin   |



## Mission Implementation

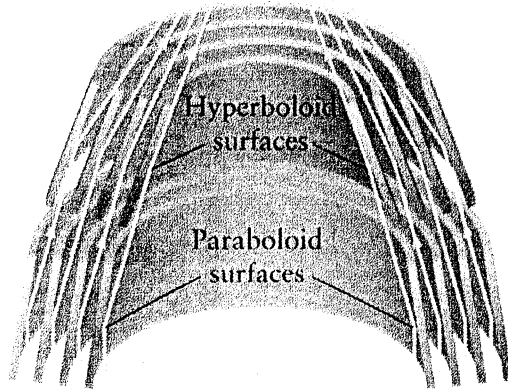
- To meet the requirements, our technical implementation consists of:
  - 4 SXTs each consisting of a Flight Mirror Assembly (FMA) and a X-ray Microcalorimeter Spectrometer (XMS)
    - Covers the bandpass from 0.6 to 10 keV
  - Two additional systems extend the bandpass:
    - X-ray Grating Spectrometer (XGS) – dispersive from 0.3 to 1 keV (included in one or two SXT's)
    - Hard X-ray Telescope (HXT) – non-dispersive from 6 to 40 keV
- Instruments operate simultaneously:
  - Power, telemetry, and other resources sized accordingly

### 4 Spectroscopy X-ray Telescopes



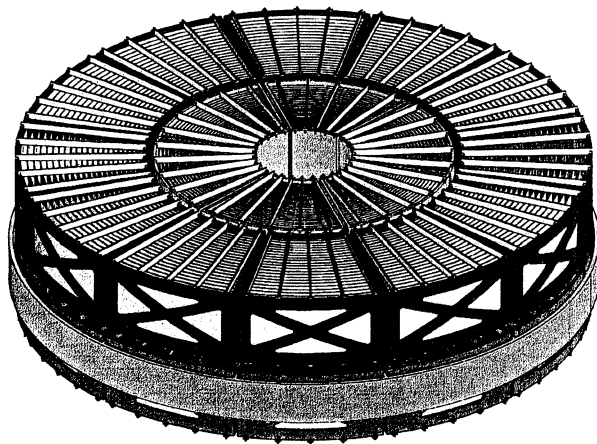
## Spectroscopy X-ray Telescope (SXT)

Focus



X-rays

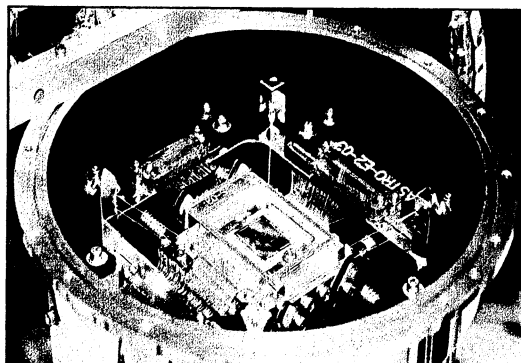
X-rays



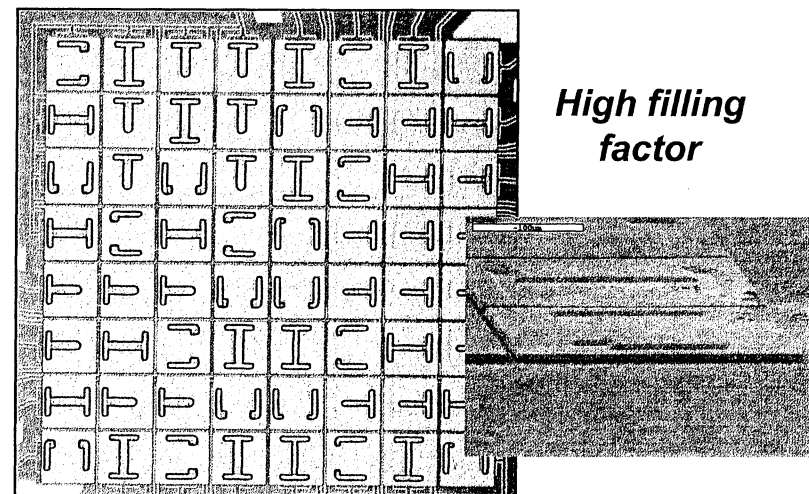
- Trade-off between collecting area and angular resolution
- The 0.5 arcsec angular resolution state of the art is *Chandra*
  - Small number of thick, highly polished substrates leads to a very expensive and heavy mirror with modest area
- Constellation-X collecting area (~10 times larger than *Chandra*) combined with high efficiency microcalorimeters increases throughput for high resolution spectroscopy by a factor of 100
  - 15 arcsec angular resolution required to meet science objectives (5 arcsec is goal)
  - Thin, replicated segments pioneered by ASCA and Suzaku provide high aperture filling factor and low 1 kg/m<sup>2</sup> areal density

## X-ray Microcalorimeter Spectrometer (XMS)

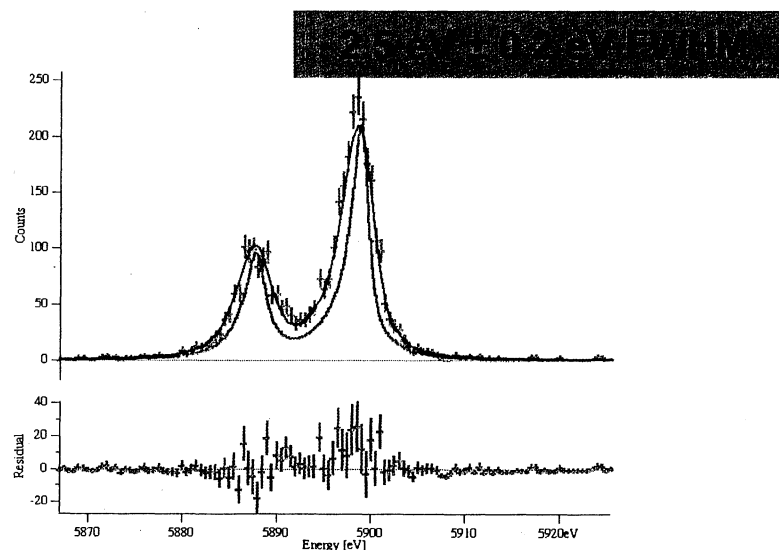
- X-ray Microcalorimeter: thermal detection of individual X-ray photons
  - High spectral resolution
  - $\Delta E$  very nearly constant with  $E$
  - High intrinsic quantum efficiency
  - Non-dispersive — spectral resolution not affected by source angular size
- Transition Edge Sensor (TES), NTD/Ge and magnetic microcalorimeter technologies under development



*Suzaku X-ray calorimeter array achieved 7 eV resolution on orbit*



*8 x 8 development Transition Edge Sensor array: 250  $\mu\text{m}$  pixels*



## Current Status

- **Constellation-X is an approved NASA astrophysics mission, currently pre-phase A with the focus on technology development and optimizing the mission configuration**
  - Recently completed a reconfiguration study that streamlined the mission configuration and maintained the science goals
- **Constellation-X is the next major NASA astrophysics observatory, to follow after JWST (2013 launch), based on its ranking in the 2000 Decadal survey - budget wedge opens around 2009/2010 with 2017/18 the earliest realistic launch date**
- **A National Academy Review is currently examining the five Beyond Einstein missions (Con-X, LISA, JDEM, Black Hole Finder, Inflation Probe) to resolve conflicting advice between 2000 Decadal Survey and Quarks to Cosmos Academy reports and will recommend in Sept 2007:**
  - which Beyond Einstein mission should be launched first, and
  - technology investments for the 2010 decadal survey

## Summary

- **Constellation-X opens the window of X-ray spectroscopy with a two order of magnitude gain in capability over current missions**
- **Two science goals driving the need for this new capability are:**
  - **Black Holes: precision tests of GR in the strong field limit and determination of Black Hole spin in a large sample**
  - **Neutron Stars: Precision measurements of the mass-radius relation of neutron stars to determine the Equation of State (EOS) of ultra-dense matter**
- **Constellation-X is a Great Observatory that will enable a broad range of science that will engage a large community — Astrophysicists, Cosmologists, and Physicists through an open General Observer Program**

**<http://constellation.gsfc.nasa.gov>**